SCIENCE FOR GLASS PRODUCTION

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DISTRIBUTION OF FRESHLY MELTED GLASS IN A GLASS BAND

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The study analyzes the conditions of the distribution of the indicator (yttrium oxide introduced together with the batch) across and inside the glass band produced on top of molten metal. It is demonstrated that freshly melted tagged melt exists in the depth of the glass band in the form of luminescent layers, whose number increases with time, up to the uniform distribution of the indicator in the band. It is established that lateral convection in the glass melt has a determining effect on the distribution of tagged glass in the glass band.

One of the reasons for imperfect quality and optical distortions in thermally polished glass consists of deviations in the batch composition together with a high efficiency of the tank furnace, which results in poorly melted and non-homogenized glass melt arriving at the working zone. Such melt contains areas rich in SiO_2. This, in turn, leads to the formation of cords and heterogeneities of various sizes within the glass band, which causes the deformation of the glass-band surface and, accordingly, optical distortions.

The glass-melt convection in a glass-melting tank furnace has the determining effect on the homogenization of glass. This calls for detailed studies of the mass-exchange process in the melt. As the contemporary glass-melting furnaces are little accessible for observation, the study of mass exchange employing indicators is of special importance. In particular, this method makes it possible to identify the location of freshly melted glass produced from poor-quality batch in the glass band.

The fundamental regularities of the exit of freshly melted (indicator-marked) glass in vertical glass drawing are described in [1]. However, the regularities of glass-melt distribution in a glass band molded over molten metal are currently of greater interest. Accordingly, the study in [2] considered the conditions of the exit of tagged glass melt across the width of the band when observed from above. The purpose of the present study is to describe the results observing the glass-melt distribution over the depth of the band, with the melt exiting from different zones across the tank width.

The studies were carried out using the known method [1, 3]. A novel factor was feeding the indicator via different (lateral or central) batch chargers, which made it possible to observe the regularities of the band formation from melt arriving from different sites across the tank width.

The conditions of distribution of the indicator over the band thickness were studied on glass ribbons cut across the entire width of the glass band. The average concentration of the indicator was determined for each fifth of the band width. The main parameters of the exit of marked glass melt toward the band are given in Table 1.

The qualitative aspect of the indicator distribution in the band is as follows. The first portions of the tagged melt are detected in the band 7 – 8 h on the average after the tagged

TABLE 1

Furnace characteristics and indicator migration parameters	Conditions of feeding the indicator via chargers		
	all chargers	two central ones	two lateral ones
Furnace output, tons/day	285	285	298
Time of the first batch of the indicator reaching the discharge area, h	7.0	8.0	8.5
Average speed of arrival of the first batch of the indicator on the band since the moment of charging, m/h	8.9	8.3	7.8
Time of indicator concentration reaching its maximum level, h	40	90	80
Time of working glass melt containing the maximum amount of the indicator, h	155	96	92
Time of complete removal of the indicator from the glass band, h	1248	1152	120

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batch was charged. The indicator is observed in the areas near the side edges of the band, and gradually it fills the central zone. The time difference between the appearance of the first luminescent layers near the edges and in the middle of the band is approximately 2 – 6 h.

The indicator is most often arranged on the upper surface of the band in the form of thin parallel layers, which gradually fill the entire bulk of the band from the top to the bottom surface. At the same time, the layer with the highest concentration of the indicator remains on the surface of the glass band.

The number of layers in the central part of the band in all experiments turned out to be half of the number of layers near the edges. This difference persisted during the whole experiment, up to the complete disappearance of all layers.

Light blue uniform luminescence was observed over the entire thickness of the band about 40 h after the indicator was placed into the tank, and certain layers with a higher concentration of the indicator were visible on the background of this luminescence. Then, as single luminescent layers were extended into the depth of the band and the average concentration of the indicator in glass decreased, the luminosity of the background became brighter.

The expansion of the indicator in the lower part of the band occurred also from the edges toward its center, which is evidence of the fact that the indicator in the discharge area and in the beginning of the float tank is drawn from the surface flows toward the side walls.

After 70 – 80 h had passed since the introduction of the indicator into the tank and homogenization of its concentration in single layers and in the main bulk of glass, non-luminescent dark melt stripes appeared in the near-edge sites of the upper part of the band.

The laminar arrangement of the indicator within the glass band, the gradual increase in the number of these layers, the transition to uniform luminescence of the band in all its bulk, and the formation of dark stripes of substituting indicator-free glass, which expand from the surface towards the inner layers of the band, all this to a large extent coincides with the regularities described for vertical drawing melting tanks [1]. Accordingly, it was necessary to specify the conditions for the appearance of the first portions of tagged glass melt in the side portions of the glass band, as well as the reasons for the difference in the number of marked glass layers across the band width. Explaining this by the similarity to the fact that the tagged glass melt first of all arrives at the lateral machines in vertical drawing systems, which was observed by various researchers [1, 4], needs to be verified, since under those conditions this could be due to the shorter routes covered by glass flows to reach the lateral machines.

In order to determine whether the above-described distribution of the first portions of the indicator in the glass band correlates with certain regularities of the migration of individual glass-melt streams along the tank, the specifics of the marked glass position in the band was investigated, with the indicator-marked batch being fed via the central chargers and via the lateral chargers separately. Altogether, three variants of introducing the indicator into the tank were studied: via all chargers, via the two central ones, and via two lateral ones (Table 1).

It was found that the indicator launched through the central chargers first appeared in the surface layers in the side areas of the band (around 1 m wide) and only 2 – 6 h later was seen in the surface layers of the central part of the band.

It should be stressed that when the indicator was launched via the lateral chargers, the luminescent layers also were first observed in the upper part of the band in the side areas. Next, the marked layers propagated across the entire thickness and width of the band, whereas the greater number of layers was registered in the half of the band on which side the indicator had been launched. At the same time, the difference between the two sides of the band in lateral launching of the indictor was manifested in the fact that a dark non-luminescent zone was seen for 10 – 11 days in the bottom part on the opposite side of the glass band. This is the evidence of the fact that the indicator from this side of the furnace never penetrated into the opposite part of the band.

Thus, no fundamental difference between the central and lateral launching of the indicator was identified with respect to the position of the indicator across the band. The main feature consists of the existence of a great number of thin luminescent glass layers in the side areas of the band, including the case of the central launching of the indicator. At the same time, among the three investigated variants of introducing the indicator into the tank, its launching through all chargers ensures its most uniform distribution across the band width. On the one hand, this may signify that the introduction of the indicator through all chargers smoothed the qualitative differences in the exit of the indicator toward the central and side parts of the band. On the other hand, the observed differences in the position of the marked melt across the band could be caused by the differences in melted glass trajectories in different areas of the melt across the tank width, different degree of glass melt circulation, and, accordingly, different homogenization in the melting tank.

To substantiate this assumption, one can consider the mass-transfer parameters given in Table 1. It can be seen that the time of arrival of the first portion of the indicator to the band, as the marked batch is launched through only central or only lateral chargers, is slightly longer (by 1 h) than when the marked batch is supplied through all chargers. Accordingly, the difference in the speed of the indicator migration to the glass band along the tank is as insignificant. At the same time, one should note a higher speed of the first portion of the indicator when fed via all chargers. When this variant is used, a significant difference is registered in the time of the indicator concentration reaching its maximum level and the time of its complete removal from the tank.

The qualitative parameters in Table 1 generally indicate that the glass streams first reaching the glass band are freshly melted streams resulting from feeding of the batch with

TABLE 2

Parameter	Conditions of feeding marked batch through chargers		
	all chargers	two central ones	two lateral ones
Empirical mass-exchange curves	$\log C = -1.919 - 0.00125\tau$	$\log C = 2.295 - 0.00264\tau$	$\log C = -2.139 - 0.00153\tau$
Active volume, %	187	84	138

CeO_2 via all chargers. These flows are the most active and persist in the glass band for a long time. When the indicator is launched in thinner stripes, the differences in migration routes are not evident enough. On the whole, no full correlation was established between the qualitative situation of the indicator behavior in the glass band and the quantitative mass-exchange parameters. The same was noted in [1].

Since the melting zone in wide tanks has a specific configuration (this zone is shorter in the middle of the tank than near the side walls), one could expect the formation of a glass-melt flow, which would entrain insufficiently melted and poorly homogenized fluid glass at a high speed toward the working zone. However, the results of the present study indicate that the exit speed of marked glass melt from the central chargers is somewhat lower than the speed of the indicator arriving at the band when launched through all chargers, i.e., the glass melt that arrives at the glass band the earliest is not from the central chargers. The same fact is supported by the time needed by the concentration of the indicator to reach its maximum level: in the first experiment (the indicator launched through all chargers), this time was shorter than in the other two experiments.

Thus, no anomalies were revealed in the migration of the central glass melt flow with respect to the exit speed of the first portions of the indicator.

For better understanding of the described phenomena, one can use the mass-exchange parameters, which make it easier to observe the glass-melt circulation in the tank. By comparing the time of the complete exit of the indicator onto the glass band, it can be seen that when the indicator is launched via all chargers, the period of removal of the indicator from the band is the longest. In this case, it can be assumed that the glass melted from the batch fed through the central chargers remains on the band for a shorter period and, consequently, is less homogenized in the tank.

To substantiate this idea, the empirical equations for the descending branches in mass-exchange curves were calculated (Table 2). The use of these curves was described earlier [5, 6]. In these equations, the factor at τ (time) characterizes the rate of decrease in the indicator concentration C, which can be used to determine the active volume of the melting furnace.

It can be seen that in the case of launching the indicator through all chargers or through lateral chargers the factor at τ is of smaller importance than in the case of its central launching. Accordingly, the glass-melt flows made of the batch from the central chargers have a different homogenization mechanism. This means that whereas glass melt made of the batch from the central chargers circulates only along the tank axis the melt made of the batch from the lateral chargers participates both in the circulation along the tank axis, and in mixing in the lateral convection flows. This, in turn, can affect the glass-band quality with respect to optical distortions in the middle part of the band.

Thus, the lateral convection plays a substantial role in the distribution of freshly melted glass across the band width, and its significance is considerably higher in wide tanks. It can be assumed that lateral convection in the working channels and at the stage of spreading in the float tank has an effect on entraining the first portions of tagged glass melt and contributes to the quantitative parameters of mass transfer.

The arrival of the indicator at the glass band in the form of layers suggests that heterogeneous glass melt from a low-quality batch will exist in layers inside the glass band, with the maximum concentration near the upper surface of the band, which can create edge stresses and lead to the deformation of the band in the form of planar distortion. This phenomenon is expected to be registered 8 – 12 h after an imperfect batch is charged into the tank.

Although this article describes the behavior of glass-melt flows in a furnace for sheet glass, the same phenomena will be observed in any glass-melting tank, only manifested to a different extent, depending on the size and width of the tank, as well as the furnace output.

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